Architectural and Behavioral Systems Design Methodology and Analysis for Optimal Habitation in a Volume-Limited Spacecraft for Long Duration Flights

Psychology in Architecture Conference
University of Texas
December 2016

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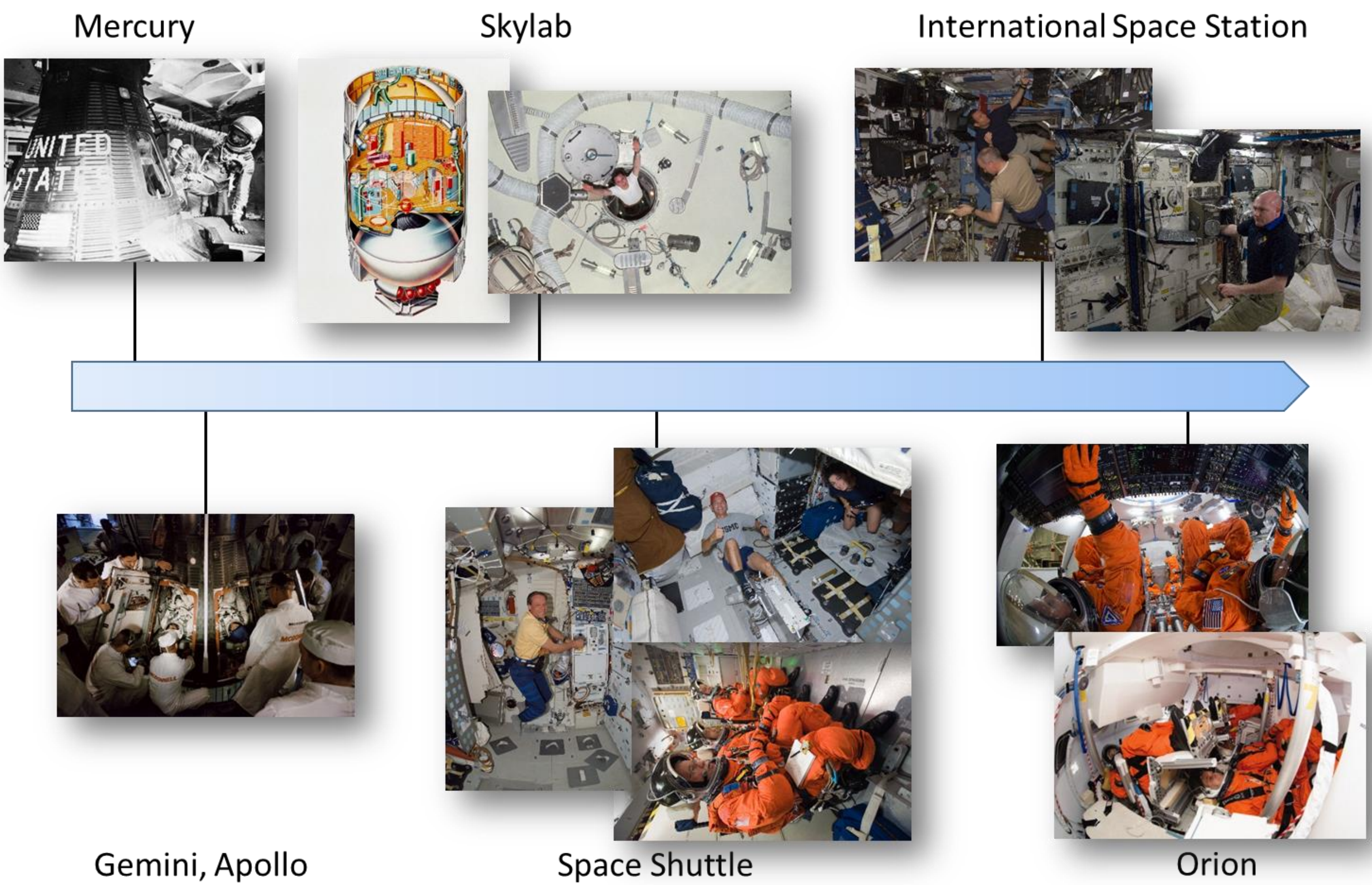
History of Spacecraft Affect on Behavior

Evidence shows that architectural arrangement and habitability elements impact crew behavior and health



Hazards and Risks of Spaceflight

Isolation & Confinement

Cognitive or Behavioral Conditions and Psychiatric Disorders

Sleep Disorders

Team Cooperation, Coordination, Communication, and Psychosocial Adaptation

Altered Gravity

Balance Disorders

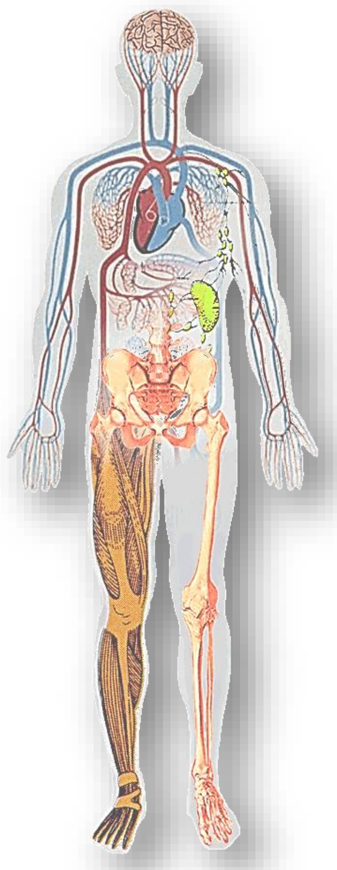
Fluid Shifts

Cardiovascular Deconditioning

Vision Impairment

Muscle Atrophy

Bone Loss



Hostile/Closed Environment

Vehicle Design

Sleep Loss

Circadian Desynchronization

Work Overload

Human-Computer Interaction

CO_2 Levels

Toxic Exposures

Water

Food, Nutrition

Space Radiation

Acute In-flight Effects

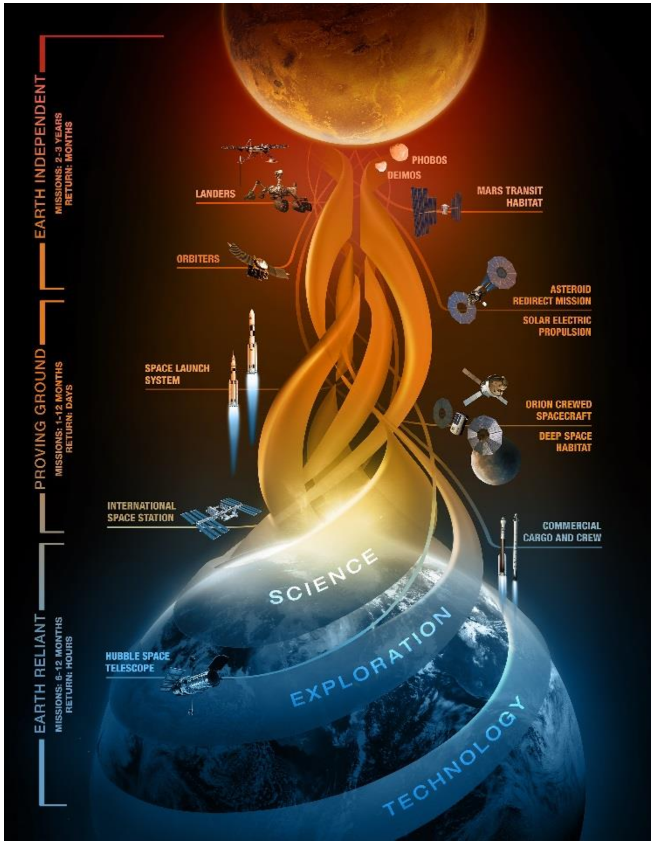
Long Term Cancer Risk

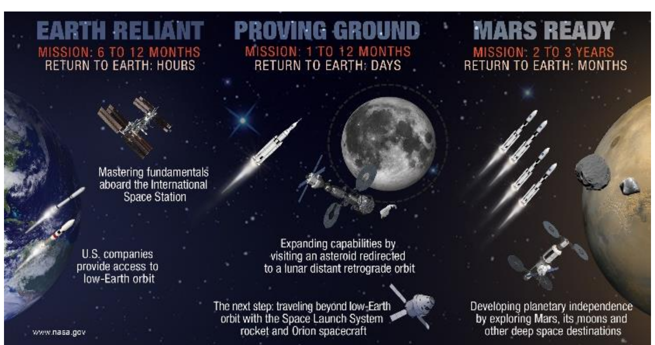
Distance from Earth

"Autonomous" medical care capacity

Pharmaceutical Efficacy

Human Spaceflight Journey to/from Mars

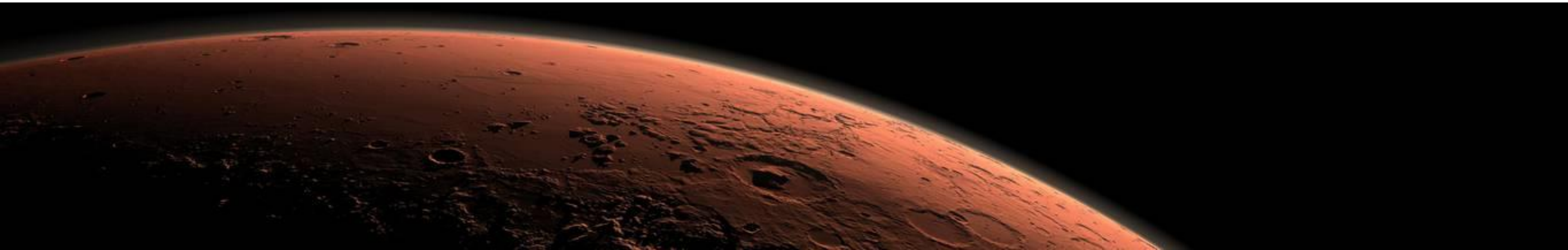




- Several mission options for advancing human spaceflight leading to human presence on and exploration of Mars are under consideration
- As part of these options, humans will occupy deep space, i.e. beyond the International Space Station outside of the Earth's protective magnetosphere, with increasing mission durations
  - To develop and test propulsion and life-critical technologies and practice techniques for Mars habitation
  - To understand and mitigate impact of habitation variables, e.g. isolation, dormancy
  - To understand and mitigate negative impact of environmental variables, e.g. radiation exposure
- **In each environment, in transit, or on a planet's surface, what is the most effective volume and architectural arrangement of that volume to promote optimal crew behavioral health?**

Psychology of Long Term Isolation and Confinement

- Astronauts perform well and thrive on 6 month International Space Station missions
- Stressors of long duration exploration missions greater than 6 months, such as a trip to/from Mars, will introduce a new paradigm
  - isolation and confinement for extended durations
  - remote distances will require autonomous operations
- Research from long duration isolation and confinement expeditions (e.g. Antarctic Stations) reveals psychiatric diagnoses (e.g. depression) which in some cases may have led to evacuations



Determining Minimally Acceptable Net Habitable Volume

- The volume and habitability recommendations for future spaceflight habitats is based on functional task analyses and behavioral considerations
- Correlation of minimally acceptable net habitable volume to mission duration is not evident
- There is insufficient data to support a correlation of mission location to minimally acceptable net habitable volume
- Thus, determination of minimally acceptable net habitable volume may be based on factors such as:
  - Mission parameters
  - Crew tasks
  - Potential multi-functional areas and co-location of tasks

Notional Mission to Mars Parameters	
Total Mission Duration	30 months: 6 months to Mars, 18 months on Mars, 6 months from Mars
Crew Size	6
Crew Composition	pilot, physician, geologist, biologist, engineers
Gender Mix	Variable; undefined
Cultural Mix	International
Mission Tempo	Long periods of low mission tempo, interspersed with high activity
Communication Delays	Up to 22 minutes one-way with blackout periods
Autonomy from Ground	Increasing en route to Mars, decreasing during return to Earth

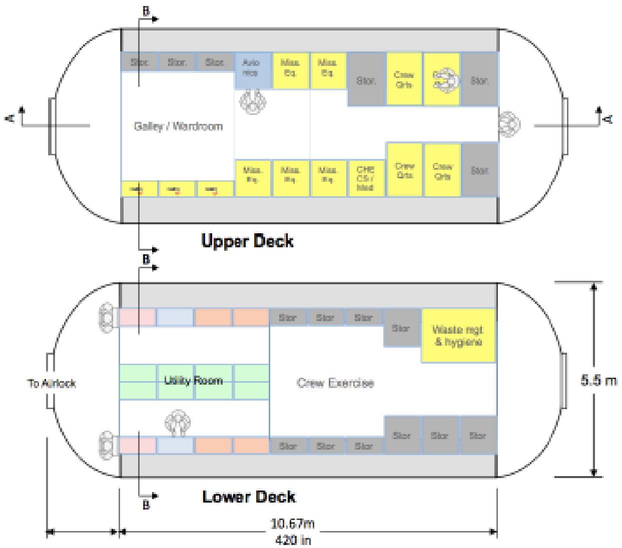
Private Quarters Sleep Space | *Dining Communal* | *Workspace* | *Exercise Recreation* | *Suit Donning* | *Medical Care* | *Hygiene* | *Translation Circulation* | *Stowage Access*

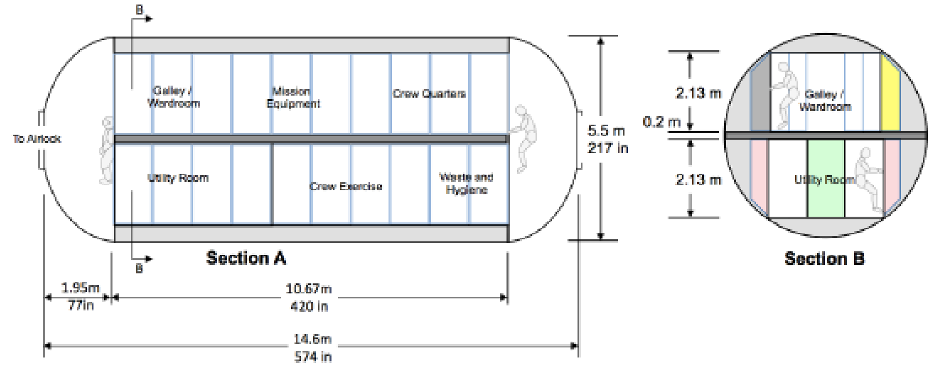
Current NASA-Supported Research and Activities

- Effects of prolonged isolation and confinement, as well as mitigation strategies to support liveability, well being and performance
  - Volume, layout, and design recommendations for specific work areas
  - Food systems that support individual and team health (e.g. facilitate group dining)
  - Optimal lighting to support aesthetics of the environment, visual task performance, and importantly, help maintain circadian rhythms and sleep-wake cycles
- Formulation of a variety of transit and surface spacecraft layouts to accommodate functions, mass and volume constraints, human performance, health, and safety

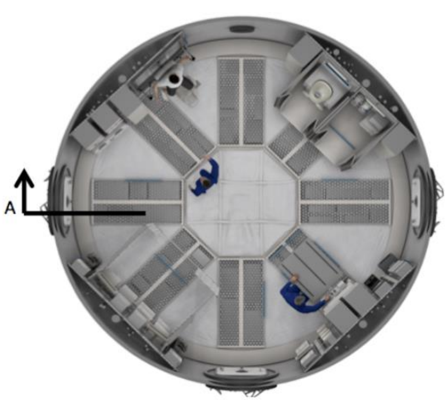
Notional Arrangements and Considerations for Transit Habitat

Notional Longitudinal Arrangements

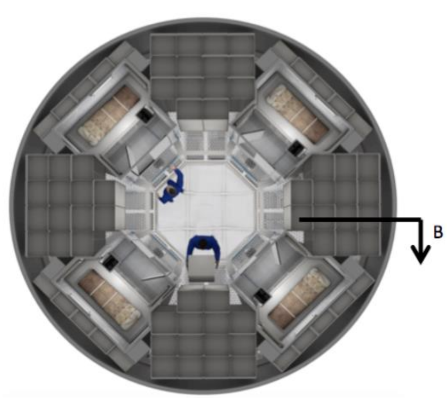




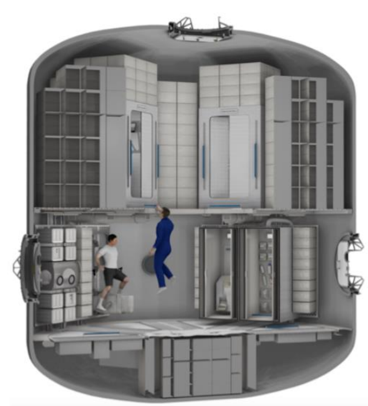
Notional Vertical/Axial Arrangements



Lower Deck



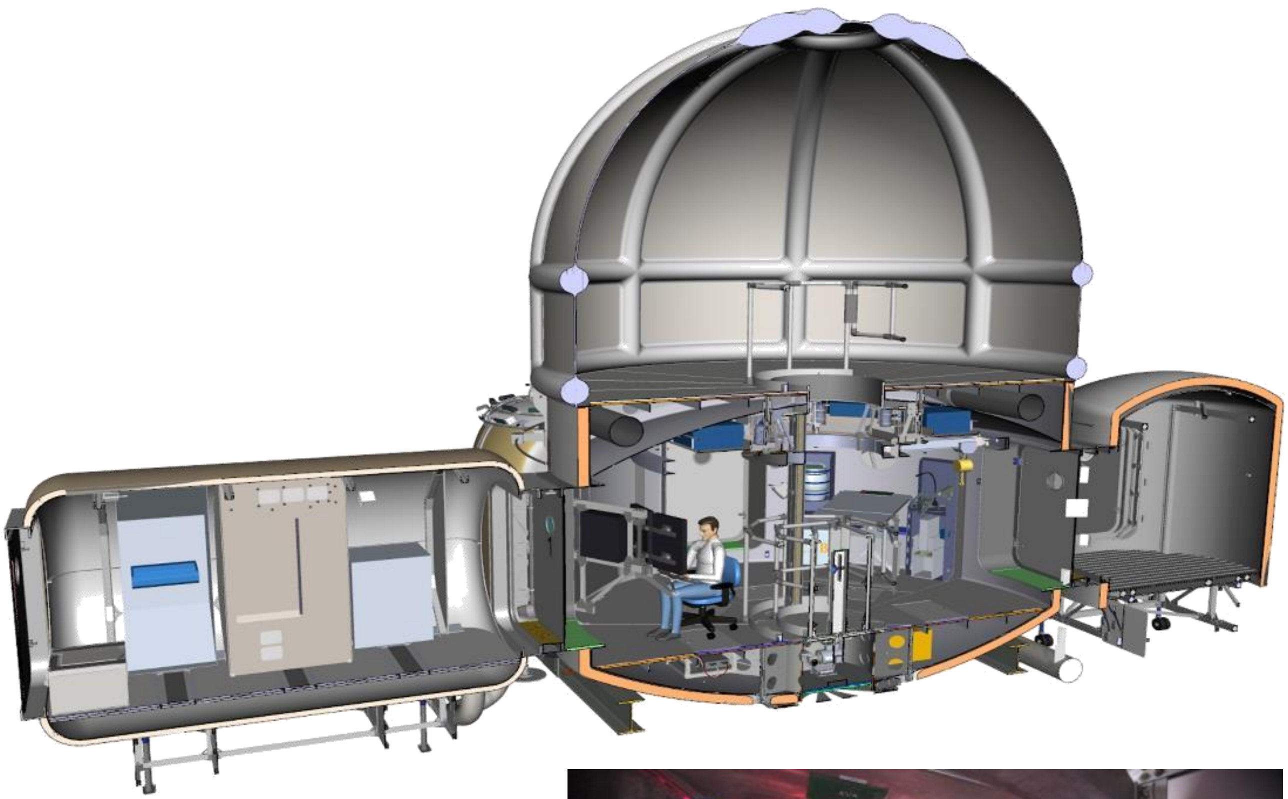
Upper Deck



Section A

Section B

Notional Arrangements and Considerations for Surface Habitat



Psychological and Architectural Design Integration

- Future human spaceflight mission conditions impact architecture and psychological responses
  - Limited overall volume and small unit volumes
  - Small number of crew
  - Transitions from Earth Reliant to Earth Independence
- The unique environment of space demands special considerations be taken into account for optimal habitation design
  - Environmental conditions (e.g., noise, vibration, lighting)
  - Human physical capabilities and limitations (e.g., anthropometry, strength)
  - Psychosocial considerations
- Specific concerns to maintain psychological health and well-being
  - Sizing of functional areas, especially crew quarters
  - Appropriate allocation of private and public spaces
  - Functional and hardware layout to accommodate “live”, “play”, and “work”
  - Optimize usability: efficiency, effectiveness, and satisfaction for users

Additional Architectural Design Considerations

- Volume is defined by the functions required of the mission
- Potential paradigm shift to larger inflatable/expandable pressure vessels/habitats
- Habitation design features
  - Internal Aesthetics
  - Functional Allocations
  - Use of materials
  - Use of lighting
  - Creation of private and social spaces
  - Separation of noisy and quiet zones
  - Separation of “dirty” and clean zones
  - Separation of “living” and “working” zones
  - Line of Sight
  - Local Vertical